Effect of Hydrothermal Treatment on the Improvement of Wheat and Triticale Grain Properties

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Summary

Since ancient times, grain has been used for human consumption and feeding of animals. In post-harvest cereal technology, it is important to process and store the grain well, in order to maintain quality until use. In the process of grain processing, the most important is hydrothermal processing. When processing grain for human consumption and animal nutrition, a hydrothermal steaming process is used, the so-called "cooking", which is a technological process of grain treatment with the aim of gelatinizing starch, i.e., to improve the nutritional properties and better digestibility of grain. This research presents the results of changes in the nutritional properties of wheat grains of two cultivars, Kraljica and Srpanjka, and on two cultivars of triticale, Goran and Ranko. The thermal treatment by convection drying was performed at (50°C, 60°C and 70°C), as well as the cooking process in a period of 10 and 15 minutes at a pressure of 0.5 bar. In the drying process, the Srpanjka variety released water faster than other investigated samples at all temperatures. From all the obtained results, it can be concluded that the hydrothermal treatment leads to a change in the nutritional properties of wheat and triticale, or to a change in the content of ash, fat and starch in the grain.

Key words

wheat, triticale, drying, steaming, nutritional values

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Introduction

Cereals have a major role in food security of the world (Poutanen et al., 2014). According to FAOSTAT data for 2018, wheat is grown on more than 214 million hectares in 124 countries with a production of 734 million t/ha, and triticale on almost 4 million hectares in 40 countries with a production of almost 13 million t/ha (FAO, 2020). Most wheat is grown in Asia 44.7%, Europe 33%, America 15.4%, Africa 4% and Oceania 2.9%, while as much as 89.7% of triticale is grown in Europe, 7.4% in Asia, 2.1% in the United States, 0.7% in Oceania, and 0.2% in Africa (FAO, 2020).

In the total plant production in the Republic of Croatia, the share of cereal production occupies the most important place. Family farms use 863 000 ha of arable land, of which as much as 60.75% or 524 000 hectares are occupied by cereals, which include wheat and triticale (Agriculture census, 2020). Considering the agricultural census from 2016, the area sown with cereals decreased by 1.7% and the area of arable land decreased by 19 000 ha.

In temperate countries the wheat (*Triticum aestivum* L.) is the dominant crop being used for human food and livestock feed (Shewry, 2009). The first cultivation of wheat occurred about 10 000 years ago, as part of the 'Neolithic Revolution', which saw a transition from hunting and gathering of food to settled agriculture (Heun et al., 1997; Nesbitt and Samuel, 1998; Dubcovsky and Dvorak, 2007). Wheat is a culture of colder climates, but it is also widespread in other climatic areas. In the northern hemisphere, it can grow all the way to the equator if it is grown at higher altitudes (Pospišil, 2010). It is considered a mainstay of today's human diet, being the most important source of cereal in different regions of the world such as Central Asia, Eastern Europe and Russia, Australia, West Asia, North America, North Africa (Shiferaw et al., 2013). Wheat is one of the major staple foods all over the world because of its agronomical adaptability, ability of its flour to be made into various food materials and ease of storage (Mohapatra and Rao, 2004). The protein content of wheat grain ranges from 12 to 15%, the starch content can vary from 49 to 73%, the fat content is usually from 1.5 to 3.2%, the ash content from 1.5 to 2.8% and is located in the pericarp and the aleurone layer, while in the germ it is significantly less, while phosphorus (P) and potassium (K) account for 70 to 80% of the total amount of ash elements and magnesium (Mg) for 11 to 13% (Pospišil, 2010).

Triticale (*Triticosecale ssp*), a human made crop, is a small grain hybrid produced between wheat and rye (Mergoum et al., 2009). Although a relatively new crop, the history of triticale goes back to the end of 19 century when the first crosses were attempted in Scotland. Triticale is used for food, feed, grazed or stored forage and fodder, silage, green-feed and as a potential energy crop in bioethanol production (Mergoum et al., 2009). According to Weipert (1985) it has several positive properties such as resistance to high temperatures, safe high grain yield, modest agrotechnical requirements, very good adaptability and good resistance to disease, and among the negative properties there is the problem of grain failure, reduced hectolitre weight and reduced mass of 1 000 grains. The starch content in the grain ranges from 58 to 79%, the protein content from 10 to 16%, the fat content from 1.4 to 2.1%, the sugar content from 5.5 to 6%, fiber from 2% to 3% and minerals from 1.8 to 2.2% (Pospišil, 2010).

After harvesting, wheat and triticale with a larger amount of moisture should not be stored, because their grains are subject to biochemical processes. Precisely, due to excessive moisture, mechanical damage can sometimes occur in the process of grain processing, and this already creates the conditions for easier spoilage, attack of diseases and pests. If harvesting takes place with a high moisture content, it must be artificially dried below a critical level, allowing for safe, long-term storage and eventual use (Wilcke and Hellevang, 2002).

Hydrothermal treatments are mainly used in order to improve the nutritional and physicochemical characteristics of the raw material (Filipović et al., 2003; Krička et al., 2017) and humidity reduction. There are several types of hydrothermal treatments such as drying, toasting, internal heating (infrared and microwave irradiation), pressing (dry extrusion, expanding, pelleting, roller pressing), cooking (steaming) and combining some processes (Krička et al., 2009). Energy is required for the purpose of hydrothermal processing of grain as well as for its drying. In cooking treatment, the usual technology is drying – cooking- drying of grain with the purpose of improvement of grain properties, which requires double drying.

Drying is the oldest method used in preserving agricultural products (Matin et al., 2019). The drying procedure ensures that product remains unchanged for a certain period (McLean, 1980; Krička et al., 2003; Matin et al., 2013; Matin et al, 2017). Natural drying is the process of removing moisture by solar radiation and natural airflow and is usually limited to appropriate climatic zones and certain foods. Forced (artificially) drying is drying under controlled microclimatic conditions. Also drying is possible by processes of conduction, convection, radiation and freezing. The possibilities of applying forced drying are much wider than natural (Katić, 1997; Krička et al., 2017). Drying of food material depends upon the heat and mass transfer characteristics of the product being dried. The knowledge of temperature and moisture distribution in the product is vital for equipment and process design and quality control (Mohapatra and Rao, 2004). Different moisture content and changes in chemical composition during drying process influence drying kinetics (Brooker et al., 1992; Gupta and Das, 1997; Matin et al., 2018). The speed and drying quality of agricultural products depend on environment physical characteristics, physical characteristics of the raw material, and the layer thickness (Krička et al., 2007). The essential factors for a successful drying process are moisture diffusion, activation energy (Ea), heat and mass transfer, as well as specific energy consumption (Aghbashlo and Samimi-Akhijahani, 2008). These factors can be changed by convective drying process and they are influenced by materials and drying parameters (Chayjan et al., 2011). Modelling of the drying process is most important aspects of the drying technology (Khazaei and Daneshmandi, 2007).

One of hydrotermal treatments is the cooking process, namely cooking (steaming) of the whole grain after harvesting (Putier, 1993; Mujumdar, 2000) and it is one of the essential steps in the production of starch of whole grains. Cooking is a technological process of grain treatment with the aim of gelatinizing the starch, i.e. to improve the nutritional properties and better digestibility of grain (Matin et al., 2009). During cooking of whole grains, starch granules gelatinize in their natural environment as embedded in the endosperm (Sağol et al., 2006). The purpose of cooking process is to convert the raw grain into palatable, digestible and workable form through gelatinization of starch (Voća et al., 2009).

Therefore, the aim of this research is to determine the effect of hydrothermal treatment on improvement of nutritional properties (moisture, ash, starch and oil content) of wheat (Kraljica and Srpanjka) and triticale (Goran and Ranko) grain after convection drying with three air temperatures of 50°C, 60°C and 70°C, and convection drying at the same temperatures after the cooking process on 10 and 15 minutes at 0.5 bar.

Materials and Methods

Materials

For the purpose of improving the nutritional properties of wheat and triticale grains by drying and cooking, two wheat varieties of the Agricultural Institute Osijek were used: the Kraljica variety and the Srpanjka variety and the Bc Institute triticale: the Goran variety and the Ranko variety. All investigated varieties are early or medium early varieties. The research was conducted in 2019.

Analytical Methods

Moisture content was determined according to protocol HRN ISO 6540:2002 in a laboratory dryer (Retch, Germany). Ash content was determined according to protocol HRN ISO 2171:2010 in muffle furnace (Nabertherm B170, Lilienthal, Germany). Oil content was determined according to protocol HRN ISO 6492:2011 using Soxhlet R 304 (Behr Labortechnik GmbH, Germany) while content of starch was determined according to protocol HRN ISO 6493:2001 in Polarimeter (KRÜSS, P3001, Germany), by Evers polarimetric method.

Hydrothermal Treatment

Wheat and triticale grains were rehydrated up to approximately 17,50% of moisture content, which is the average moisture content during the field harvest of grain, in order to obtain the comparability of grain for the research purpose. The rehydration process was carried out by direct action on the mass of grain with a precisely determined amount of distilled water according to the instructions of the State Institute for Standardization and Metrology. After the rehydration procedure, and before drying in the laboratory dryer, all samples' moisture content was analysed. Rehydrated samples were defined as initial samples used in further research.

Drying

The drying treatment was carried out by using a laboratory dryer. The laboratory dryer was constructed in such a way as to be kinetically similar to a real-life industrial dryer. The dryer consisted of a centrifugal fan, an electric heater, air filter and an electronic proportional controller. The fan sucks in the surrounding air and after entering the lower part of the dryer the air passes through a perforated sheet and a dense mesh to homogenize the air flow field into another round unit. Here the air is heated and directed towards the narrowed part of the dryer. A third unit, a round-patterned vessel, is inserted into the narrowed part. A thick steel mesh is installed at the bottom of the vessel. The electric heater is supplied with alternating current, with the possibility of adjusting the voltage and thus the temperature of the drying air. The voltage is manually adjusted on the control transformer, and the voltmeter, ammeter and wattmeter are connected to the electrical circuit. The set air temperature is measured using a PT 100 probe just before grain entering. The air velocity after passing through the grain layer is measured with a digital anemometer (Krička and Pliestić, 1994). The air velocity in the dryer was maintained at 1.0 m/s, and the wheat and triticale grains were dried at three air temperatures 50°C, 60°C and 70°C. Before drying, the mass and moisture content of both varieties of wheat and triticale was determined and every 5 minutes the mass loss was measured using a technical scale, i.e., the water and mass loss was calculated. All measurements were carried out in triplicates and the average moisture ratio at each value was used for calculation of drying equations.

Cooking

The cooking treatment was carried out by using a laboratory cooking device which consisted of a hermetically sealed high-pressure vessel. The vessel contained an additional pore under which a perforated substrate made of aluminum was placed which prevented direct contact of the grain with water and high temperatures. The vessel also contained an additional vessel with a porous bottom beneath which there was a perforated substrate that prevented direct contact of the grain with water and high temperatures. A thermometer and manometer for temperature and pressure control, a valve for releasing excess steam and a safety valve were installed in the vessel (Matin et al., 2009). In this high-pressure vessel, the grains were treated with steam in two different ways for 10 min (C1) and 15 min (C2) at pressure of 0.5 bar.

Statistical Analysis

Statistical analysis of the data was performed using a one-way ANOVA with Tukey's multiple comparison test ($P < 0.05$).

Results and Discussion

Determining the content of moisture in grain is important because of the effect of moisture on its physical and chemical properties. Moisture is also of great importance for the safe storage of samples and their products regarding microorganisms (Hoseney, 1994). Table 1 shows moisture content of wheat and triticale grains. The content of moisture after rehydration will be further used as the initial moisture.

The moisture content of raw wheat and triticale grains was similar and ranged from 10% to 13% in wheat and from 10% to 12% in triticale and all values were significantly different (Table 1). According to literature, Krička et al. (2012) state a moisture content of 10% to 14% in wheat, while Karunakaran et al. (2001) state a higher content of 15 to 19%. Kweon et al. (2009) and Izydorczyk et al. (2012) state that the moisture content in triticale grain is from 13% to 16,5%, depending on the grain hardness and the ash content. In this research, lower values were obtained than those recorded in literature and a possible reason for this is the influence of sort and agroclimatic growing conditions. After rehydration, the content of moisture in wheat grain and triticale increased to above 17%.

Table 1. Moisture content of wheat and triticale grain

Moisture (%)	Wheat		Triticale	
	Kraljica	Srpanjka	Goran	Ranko
Raw material	10.00[a]	12.81[c]	10.06[a]	11.91[b]
Rehydrated samples	17.56[c]	17.49[b]	17.50[bc]	17.18[a]
After cooking (0.5 bar, 10 min.)	29.62[c]	27.89[b]	31.46[d]	27.68[a]
After cooking (0.5 bar, 15 min.)	20.17[a]	22.76[b]	26.27[d]	24.82[c]
p	<0.001	<0,001	<0,001	<0,001

Note: [a,b,c] Different letters within a column indicate significant differences at the 5% level

ANOVA with Tukey's multiple comparison test ($P < 0.05$)

It was observed that all investigated sorts cooked for 10 minutes had an increased moisture content in the grain, wheat and triticale alike. Thus, it can be determined that the application of cooking treatment will increase initial moisture content in grain, which will certainly result in extended time of water release from the sorts observed. The cause of slower moisture release may be associated with the disruption of the capillary structure of the grain due to elevated temperatures and pressures to which the grain is exposed. In Pliestić and Kovačev (1999) analysis of the results of mutual comparison of grains treated with cooking and rehydration grain, it was found that the treated grain in the drying process was slower to release moisture from untreated grain, i.e. that the cooking process prolonged the drying process. Krička et al. (2000) also states that wheat grain treated with cooking process releases moisture more slowly during the drying process than the grain that has been dried by the classical method. They also mention that the cause of the slower release of moisture may be related to the disruption of the capillary structure of the grain due to elevated temperatures and the pressure at which the grain is exposed.

During the drying process, the temperature, flow rate and mass of the sample were monitored every 5 minutes and based on these data the exponential equation for drying was made, and these results are shown in Table 2.

The analysis of the results of the investigated wheat and triticale grain and air-drying temperatures presented in Table 2 displays the differences in water release rates. Based on the above presented exponential equation for drying, it can be determined that variety Srpanjka has the fastest water release from other investigation sorts at all temperatures. This is corroborated by shorter time needed for water release and a higher exponent value. Namely, the exponents show the tendency of drying rate and with a higher exponent value the drying is faster (Krička, 1993). In all investigated exponential equations, the determination coefficient between 0.850 and 0.973 was found, which corroborates the fact that the investigated seed water releases were conducted with precision and that the results were mutually comparable. This is also confirmed by a comparison with literature data for wheat grain drying (Gastón et al., 2002) triticale grain drying (Agha et al., 2014), corn kernel drying (Krička and Pliestić, 1994; Doymaz and Pala, 2003), sunflover seed drying (Matin et al., 2017). After determining the moisture content and the drying equation of wheat and triticale grain in Table 3, the content of ash, oil and starch was determined on raw material.

According to the results in Table 3, the ash (1,81%) and oil (12,66%) content is higher in triticale sample variety Goran, while starch content is higher in wheat sample variety Kraljica (55,07%). Cereals contain from 1.17 to 35.5% of fat (Mandge, 2011) and from 55 to 75% of starch (Kulp and Ponte 2000). Burešová et al, (2010) state the content of the starch is from 62,4–70,9%. According to Pettersson and Åman (1988) wheat grain contains 1,5% ash, 6,2% oil and 43,4% starch, and triticale grain 1,8% ash, 6,4% oil and 45,5% starch. These are slightly different values than those obtained in this research, but Labuschagne et al. (2007) and Massaux et al. (2008) reported that content of some nutritive value is significantly affected by variety and year of cultivation. Content of ash, oil and starch of wheat and triticale grains of all varieties was determined again after hydrothermal treatment (cooking and drying) and their results are shown in Table 4.

According to the results from Table 4, all results are statistically different. Samples cooked for 10 min have a higher ash content compared to samples cooked for 15 min. Wheat variety Kraljica and triticale variety Ranko have a higher ash content than other samples. After cooking for 10 min and drying at 60°C and 70°C, oil content gradually increased in all investigated samples. The starch content was higher in the triticale samples. Drying at 70°C Goran variety had a starch content of 57,45% after 15 min of cooking and Ranko after 10 min of cooking 55,96%. After hydrothermal treatment cereals contained on average 1.78% oil, 1.91% ash and 64.24% starch (Mandge, 2011). From all the obtained results, it is evident that the cooking method leads to improving nutritional properties of wheat and triticale, i.e., to a change in the content of ash, fat and starch in the grain.

Table 2. Exponential equations of water release and coefficient of determination R^2 from wheat and triticale grain

Sample	Variety	Cooking (min)	Drying temperature (°C)	Exponential equation	Coefficient of determination (R^2)
Wheat			50	$y = 14.999e^{-0.006x}$	0.849
		/	60	$y = 15.367e^{-0.014x}$	0.862
			70	$y = 16.795e^{-0.027x}$	0.919
			50	$y = 23.831e^{-0.017x}$	0.881
	Kraljica	10	60	$y = 26.371e^{-0.029x}$	0.925
			70	$y = 28.392e^{-0.034x}$	0.977
			50	$y = 18.14e^{-0.013x}$	0.924
		15	60	$y = 18.138e^{-0.015x}$	0.943
			70	$y = 19.502e^{-0.026x}$	0.929
			50	$y = 16.807e^{-0.024x}$	0.923
		/	60	$y = 16.67e^{-0.027x}$	0.917
			70	$y = 17.541e^{-0.051x}$	0.954
			50	$y = 26.521e^{-0.027x}$	0.971
	Srpanjka	10	60	$y = 28.014e^{-0.037x}$	0.986
			70	$y = 27.888e^{-0.042x}$	0.986
			50	$y = 18.955e^{-0.015x}$	0.875
		15	60	$y = 18.828e^{-0.023x}$	0.867
			70	$y = 21.325e^{-0.034x}$	0.924
Tritikale			50	$y = 15.712e^{-0.01x}$	0.875
		/	60	$y = 17.672e^{-0.031x}$	0.964
			70	$y = 17.735e^{-0.055x}$	0.941
			50	$y = 30.843e^{-0.023x}$	0.976
	Ranko	10	60	$y = 27.452e^{-0.027x}$	0.923
			70	$y = 28.259e^{-0.044x}$	0.923
			50	$y = 21.518e^{-0.016x}$	0.882
		15	60	$y = 24.938e^{-0.027x}$	0.939
			70	$y = 24.786e^{-0.041x}$	0.911
			50	$y = 15.073e^{-0.015x}$	0.830
		/	60	$y = 16.676e^{-0.025x}$	0.923
			70	$y = 16.913e^{-0.039x}$	0.936
			50	$y = 26.995e^{-0.028x}$	0.918
	Goran	10	60	$y = 28.194e^{-0.037x}$	0.988
			70	$y = 26.517e^{-0.048x}$	0.969
			50	$y = 20.178e^{-0.015x}$	0.884
		15	60	$y = 22.196e^{-0.027x}$	0.874
			70	$y = 24.400e^{-0.044x}$	0.957

Note: y- grain moisture, x-time of water release from grain, R^2- coefficient of determination

Table 3. Content of ash, oil and starch in raw wheat and triticale samples

Sample	Variety	Ash (%)	Oil (%)	Starch (%)
Wheat	Kraljica	1.42^{ab}	11.87^{c}	55.07^{c}
	Srpanjka	1.31^{a}	9.69^{a}	53.63^{b}
Tritikale	Ranko	1.47^{b}	9.91^{b}	50.73^{a}
	Goran	1.81^{c}	12.66^{d}	53.51^{b}
	p	<0.001	<0.001	<0.001

Note: ^{a,b,c} Different letters within a column indicate significant differences at the 5% level
ANOVA with Tukey's multiple comparison test ($P < 0.05$)

Table 4. Content of moisture. ash. oil and starch in dried and cooked wheat and triticale samples

Sample	Variety	Cooking (min)	Drying temperature (˚C)	Ash	Oil	Starch
Wheat			50	1.49^{a}	7.25^{j}	52.72^{de}
		/	60	2.02d^{ef}	5.46^{g}	55.76^{i}
			70	2.08^{ef}	5.16^{f}	55.43^{h}
			50	2.37^{c}	4.73^{c}	52.06^{b}
	Kraljica	10	60	2.05^{ab}	7.25^{f}	53.02^{e}
			70	2.17^{b}	8.82^{k}	52.52^{c}
			50	2.13^{b}	4.81^{b}	50.06^{c}
		15	60	1.90^{a}	3.74^{a}	52.95^{d}
			70	1.89^{a}	5.06^{h}	53.56^{e}
			50	1.74^{b}	6.14^{h}	53.06^{f}
		/	60	1.79^{bc}	2.68^{a}	52.86^{e}
			70	1.49^{a}	4.90^{e}	52.55^{d}
			50	1.95^{a}	4.20^{b}	48.72^{a}
	Srpanjka	10	60	1.99^{ab}	5.56^{e}	53.10^{e}
			70	1.90^{a}	7.77^{g}	54.14^{f}
			50	1.79^{a}	3.71^{a}	48.80^{b}
		15	60	1.83^{a}	5.01^{c}	53.50^{e}
			70	2.39^{c}	9.84^{i}	55. 30^{f}
Tritikale			50	2.13^{f}	6.83^{i}	52.72^{de}
		/	60	1.93^{cde}	4.10^{c}	55.76^{i}
			70	2.06^{ef}	4.95^{e}	55.43^{h}
			50	2.61^{de}	5.03^{d}	53.10^{e}
	Ranko	10	60	2.70^{e}	7.36^{f}	54.47^{g}
			70	2.76^{e}	9.31^{j}	56.61^{j}
			50	2.47^{cd}	7.71^{e}	52.89^{d}
		15	60	2.40^{c}	3.62^{a}	55.78^{h}
			70	2.64^{d}	8.65^{g}	55.96^{g}

Continued

Sample	Variety	Cooking (min)	Drying temperature (°C)	Ash	Oil	Starch
			50	2.16[f]	7.83[k]	51.96[c]
		/	60	1.87[bcd]	3.63[b]	53.87[g]
			70	2.08[ef]	4.47[d]	53.02[a]
			50	2.38[c]	3.87[a]	55.66[i]
	Goran	10	60	2.37[c]	8.08[h]	52.79[d]
			70	2.42[cd]	8.86[i]	54.75[h]
			50	2.30[bc]	3.59[a]	48.43[a]
		15	60	2.29[bc]	5.56[d]	55.93[gh]
			70	2.32[bc]	9.078[f]	57.46[i]
p				**<0.001**	**<0.001**	**<0.001**

Note: [a,b,c] Different letters within a column indicate significant differences atthe 5% level
ANOVA with Tukey's multiple comparison test ($p<0.05$)

Conclusions

According to the exponential equations at temperatures of 50°C, 60°C and 70°C, it can be concluded that the wheat Kraljica variety releases water faster than other investigated samples. After hydrothermal treatment of cooking and drying, the oil content decreased, but after cooking for 10 min and drying at 60°C and 70°C, the oil content gradually increased in all investigated samples. Hydrothermal treatment increased the ash content as well as the oil content in the Karaljica wheat variant, while it decreased in other investigated samples. From all obtained results, it is evident that the hydrothermal treatment leads to the improvement of nutritional properties.

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